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**AN INVESTIGATION OF THE RCB STAR CANDIDATE GDS J0702414-023501**

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R Coronae Borealis (hereafter RCB) stars are hydrogen-deficient, carbon-rich supergiant stars. Their photometric variability is characterised by unpredictable fading events (up to  $\sim 8$  magnitudes ( $V$ )), which are thought to be caused by the formation of carbon dust (e.g. Clayton 2012). RCB stars have been shown to possess warm and bright circumstellar shells, which are readily detected at mid-infrared wavelengths. Therefore, near- and mid-infrared colour-colour diagrams and cuts can be employed as a viable and efficient method of identifying new RCB candidates (cf. e.g. Feast (1997); Alcock et al. (2001); and Tisserand (2012)).

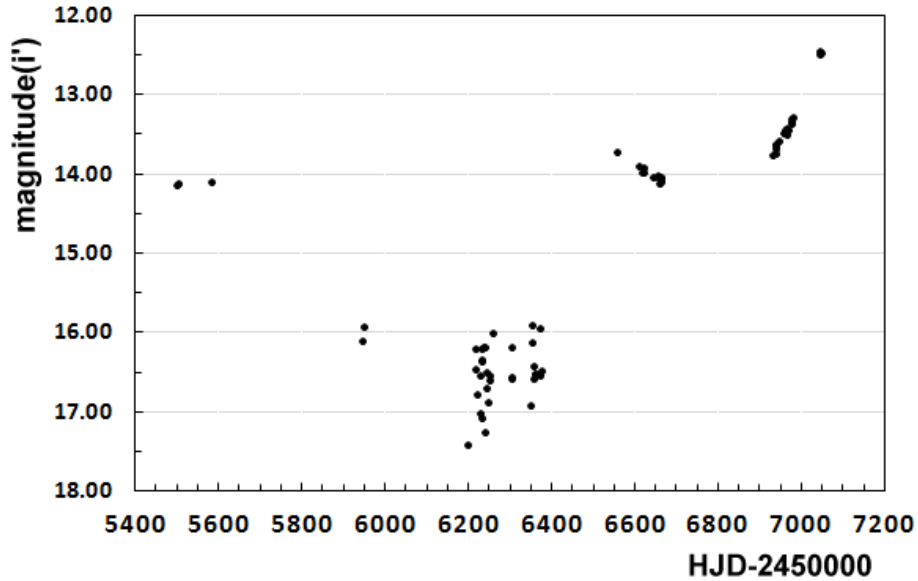
Using the above mentioned colour selection criteria, the star 2MASS J07024146-0235017 was included into the 'Catalogue enriched with R CrB stars' by Tisserand (2012). No time series photometry had been available for this object until the advent of the Bochum Galactic Disk Survey (GDS hereafter), which has been monitoring stars in a  $6^\circ$  wide strip along the Galactic plane and comprises photometry for stars in the magnitude range  $8 < r' < 18$  mag and  $7 < i' < 17$  mag. For more information on the GDS, the reader is referred to Haas et al. (2012) and Hackstein et al. (2015).

Hackstein et al. (2015) present a sample of 64 151 variable sources identified in the GDS. Among them is 2MASS J07024146-0235017, which is listed under the designation GDS J0702414-023501 with a mean magnitude of 14.15 mag ( $i'$ ) and an amplitude of 4.96 mag ( $i'$ ). No variability type was proposed by the aforementioned authors. Basic data and archival photometry of GDS J0702414-023501 are presented in Table 1; positional information was derived from the 2MASS catalogue (Skrutskie et al. 2006).

We have investigated the object because of its inclusion in the Tisserand (2012) catalogue and the observed, large-amplitude variability in GDS data. The light curve based on the current data release (Hackstein et al. 2015) is shown in Figure 1; only  $i'$  data are available for this object. Although there are only 71 data points scattered over a time span of  $\sim 1600$  days, it becomes obvious that the star's range of variability is large (approximate range of  $12.5 \text{ mag} < i' < 17 \text{ mag}$ ). Furthermore, the light curve is reminiscent of an RCB variable and seems to provide evidence against a Mira or RV Tauri classification – two types of variables that, according to our experience, contaminate the RCB-enriched catalogue of Tisserand (2012). In particular, the light curve indicates that the star's brightness has been more or less constant for about 160 days around HJD 2456300, hovering around a mean magnitude of  $\sim 16.5$  mag ( $i'$ ). Because of the available data, GDS J0702414-023501

Table 1: Table 1. Basic data and archival photometry of GDS J0702414-023501.

ID	GDS J0702414-023501, 2MASS J07024146-0235017, IRAS 07001-0230, CGCS 6197
pos (RA, Dec; J2000)	07 <sup>h</sup> 02 <sup>m</sup> 41 <sup>s</sup> .461, −02°35′01″.76
$J$ , $H$ , $K_s$ (2MASS)	11.957 mag, 9.417 mag, 7.402 mag
$W1$ , $W2$ , $W3$ , $W4$ (WISE)	5.075 mag, 3.124 mag, 2.193 mag, 1.563 mag
[9 $\mu$ m], [18 $\mu$ m] (AKARI)	8.509 Jy, 3.101 Jy
[12 $\mu$ m], [25 $\mu$ m], [60 $\mu$ m] (IRAS)	5.045 Jy, 2.387 Jy, 0.548 Jy

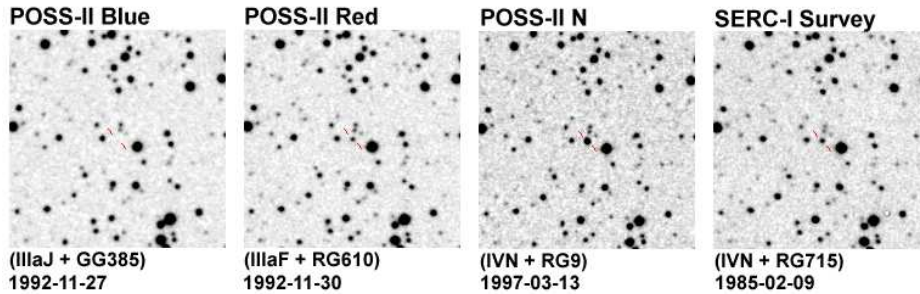


**Figure 1.** The GDS  $i'$  light curve of GDS J0702414-023501, based on the current data release (Hackstein et al. 2015).

has been listed as an RCB candidate (variability type RCB:) in the AAVSO International Variable Star Index (VSX; Watson 2006).

We have searched sky survey plate archives for the existence of exposures of the sky region of our interest (Figure 2). Unfortunately, no images are available that show the star in a very bright state, as recorded by the GDS. Nevertheless, the star is considerably brighter on *I*-band sky survey plates from 1997 than it was in 1985 (two rightmost panels in Figure 2).

Based on the calculations of Schlafly and Finkbeiner (2011), we estimate an interstellar extinction of  $A_V \approx 2.2$  mag and  $E_{B-V} \approx 0.7$  mag for the sky area of our interest. Dereddened magnitudes in the 2MASS *J*, *H*, *Ks* and WISE *W1* and *W2* bands (Cutri et al. 2012) were derived from the aforementioned source, which were used in the construction of the following colour-colour plots.



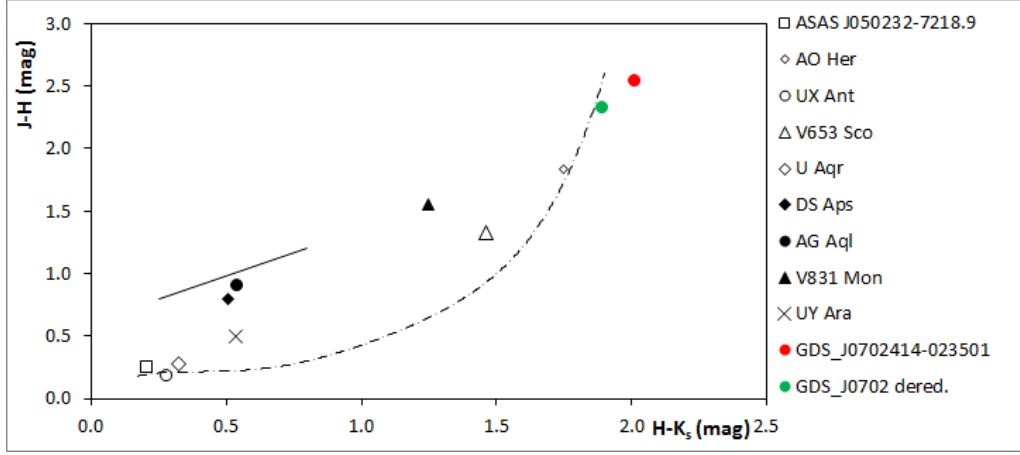
**Figure 2.** GDS J0702414-023501 on archival sky survey plates (position of the star is indicated). The captions provide information on emulsions and filters used, as well as the epoch the plate was taken.

A ( $J-H$ ) vs. ( $H-K_s$ ) diagram is shown in Figure 3. The RCB candidate GDS J0702414-023501 is indicated by the red and green dots which denote the loci of the star based on, respectively, reddened and unreddened magnitudes. Also shown are several confirmed RCB variables (open symbols), Mira variables (filled symbols) and the RV Tauri star UY Ara (cross). Classifications were taken from the GCVS (Samus et al. 2007-2016) and VSX online databases; data were drawn from the 2MASS catalogue.

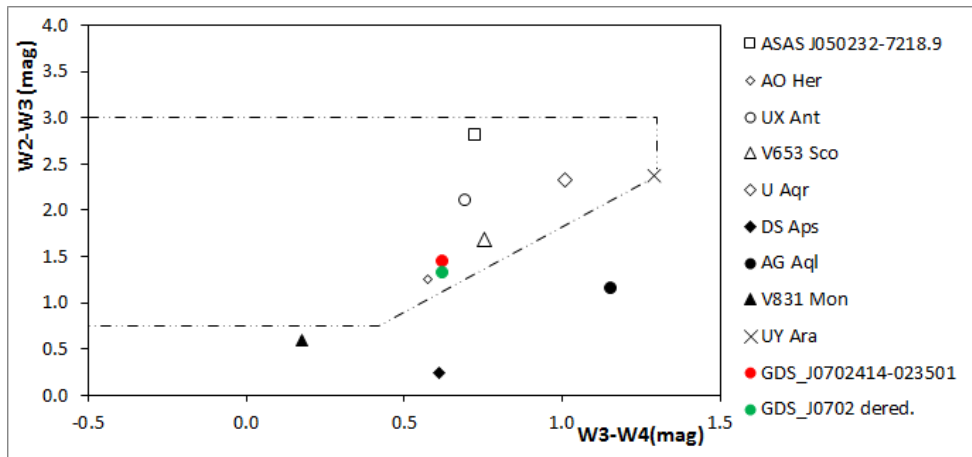
The Mira variables approximately follow the positions of SMC carbon stars (solid line), as computed by Westerlund et al. (1991) and employed in this particular context by Tisserand et al. (2004). The very red, carbon-rich Mira V831 Mon is roughly situated on an extension of this line. The RCB stars, however, follow the dashed line, which illustrates the loci of a combination of two blackbodies representing the photosphere of the star ( $\sim 5500$  K) and the dust shell ( $\sim 900$  K), as employed by Feast (1997). The represented flux ranges from ‘all star’ (lower, left end) to ‘all shell’ (upper, right end).

The position of GDS J0702414-023501 is reminiscent of the positions of RCB variables during deep obscuration minima (cf. e.g. the position of UW Cen during deep minima, indicated by the small crosses in Fig. 1 of Feast (1997)).

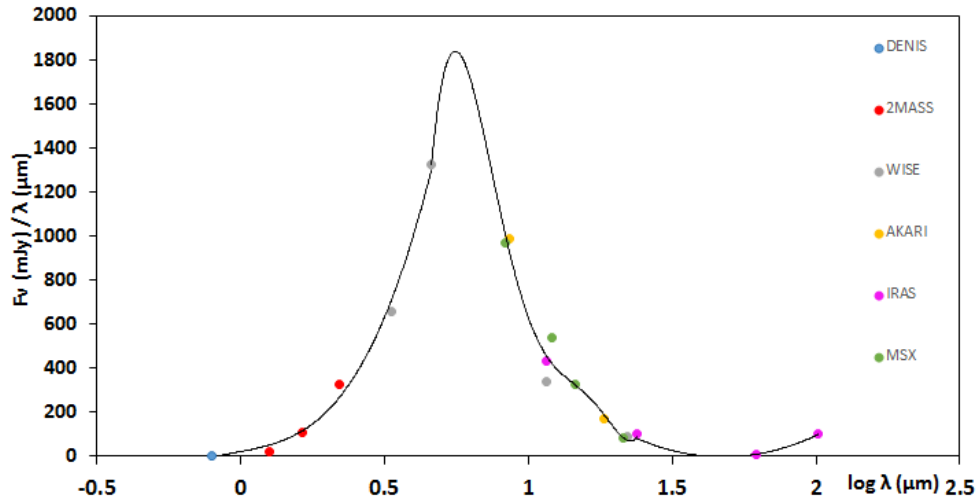
Figure 4 shows the ( $W2 - W3$ ) vs. ( $W3 - W4$ ) diagram and has been based on WISE data. Stars and symbols are the same as in Figure 3. Selection cut (1) of Tisserand (2012), which effectively identifies objects with a shell signal, is indicated by the dashed lines. Only the confirmed RCB variables and GDS J0702414-023501 are well inside the indicated area.



**Figure 3.**  $(J - H)$  vs.  $(H - K_s)$  diagram, indicating the positions of GDS J0702414-023501 (red and green dots) and several confirmed RCB variables (open symbols), Mira variables (filled symbols) and the RV Tauri star UY Ara (cross). See text for details.



**Figure 4.**  $(W2 - W3)$  vs.  $(W3 - W4)$  diagram, indicating the positions of GDS J0702414-023501 (red and green dots) and several confirmed RCB variables (open symbols), Mira variables (filled symbols) and the RV Tauri star UY Ara (cross). See text for details.



**Figure 5.** Spectral energy distribution of GDS J0702414-023501, based on data from various catalogues, as indicated in the inset legend. The solid line indicates a polynomial fit of 6th order.

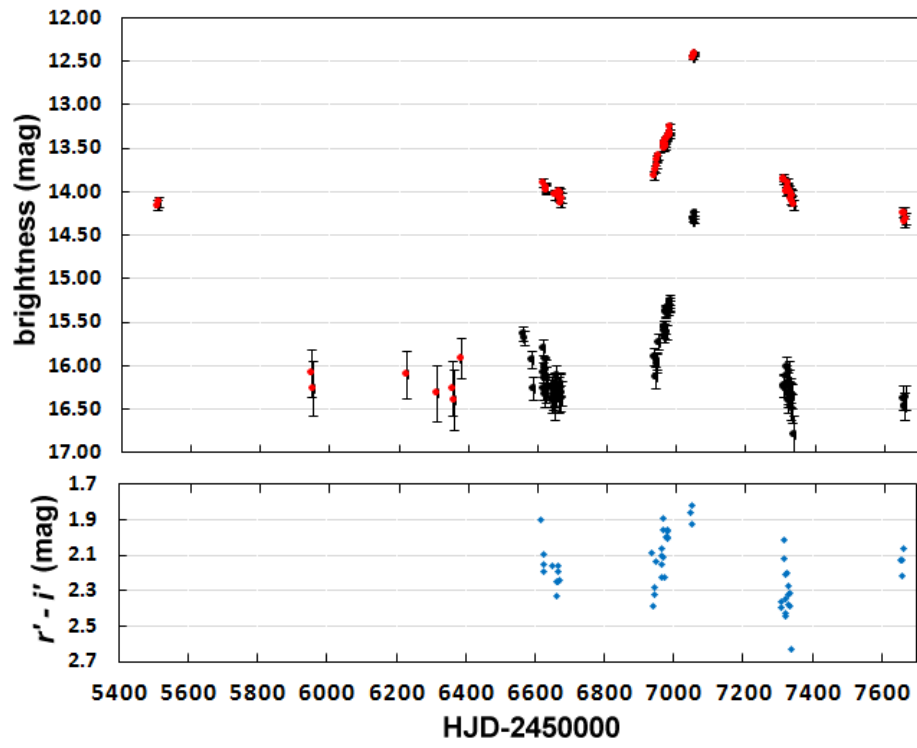
The spectral energy distribution (SED) is shown in Figure 5, which has been based on data obtained with the VizieR Photometry viewer.<sup>1</sup> The data have not been corrected for line-of-sight extinction. Note that the IRAS value at 100  $\mu\text{m}$  denotes an upper limit. An IR excess due to the presence of warm dust is clearly visible. However, the SED differs from that of typical RCB stars in that there is no indication of cold dust (cf. e.g. Fig. 6 of Tisserand et al. 2009). This does not necessarily exclude an RCB classification, as the amount and temperature of dust around the star is related to the frequency and duration of obscuration events. However, it casts doubt on the proposed variability type.

The IRAS source 07001-0230 lies 15''1 distant from the 2MASS position of GDS J0702414-023501. Interestingly, IRAS 07001-0230 was identified as a carbon star on ground of its infrared colours by Guglielmo et al. (1993) and later entered the General Catalogue of Carbon Stars as CGCS 6197 (Alksnis et al. 2001). The identification of IRAS 07001-0230 with 2MASS J07024146-0235017 = GDS J0702414-023501 seems secure (MacConnell 1993; Chen et al. 2012). In MacConnell (1993), a  $V$  magnitude of 20.0 mag is indicated for IRAS 07001-0230, which elicits the following remark from B. Skiff: “CGCS 6197, too faint ( $m_i=16.7$ )”. This may be taken as a hint at the large amplitude of variability observed in GDS J0702414-023501, which has been found as bright a 12.5 mag ( $i'$ ).

In order to shed more light on the nature of our object of interest, new and hitherto unpublished GDS data were procured (M. Hackstein, private communication), which have been based on an improved reduction procedure and extend the time baseline by  $\sim 600$  days (Figure 6). Furthermore, the new data also boast measurements in  $r'$ , thereby allowing an investigation of the colour index evolution (Figure 6, bottom panel).

The new data indicate that about 300 days after the rise to  $i' \sim 12.5$  mag (at which point the hitherto available dataset terminates), a rather sharp drop in brightness takes place. Another  $\sim 300$  days later, several datapoints suggest a further drop or rise in brightness. Moreover, the new and improved data reduction procedure significantly reduced the number of faint datapoints around HJD 2456300; what formerly looked like a phase of

<sup>1</sup><http://vizier.u-strasbg.fr/vizier/sed/>



**Figure 6.** The GDS light and colour curves of GDS J0702414-023501, based on recent, newly reduced and as yet unpublished GDS data (M. Hackstein, private communication). Red and black dots indicate, respectively, GDS  $i'$  and  $r'$  data.

approximately constant brightness (cf. Figure 1) is now down to some scattered data points and the light curve shape during this part is open to conjecture.

Generally, RCB stars show very diverse and sometimes peculiar light curves. However, the new GDS light and colour curves are strongly reminiscent of a Mira-type variable. Although the star has passed the selection criteria of Tisserand (2012) and is a confirmed carbon star, an RCB classification seems therefore unlikely; as has been pointed out above, Mira variables are known to contaminate the candidate list of Tisserand (2012).

Taking into account all available data, we propose GDS J0702414-023501 as a long-period variable of the Mira type. However, further photometric and spectroscopic studies are needed to reach a final conclusion.

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